RIVER-STAGE FORECASTS FOR THE ARKANSAS RIVER, DARDANELLE TO PINE BLUFF, ARK.

By HERMAN W. SMITH, River & Flood Division.

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The region for which river-stage forecasts have been worked out and are presented in the following paper is shown in the accompanying figure 1, which presents in outline the principal drainage channels and the positions of the main water partings of the lower Arkansas.

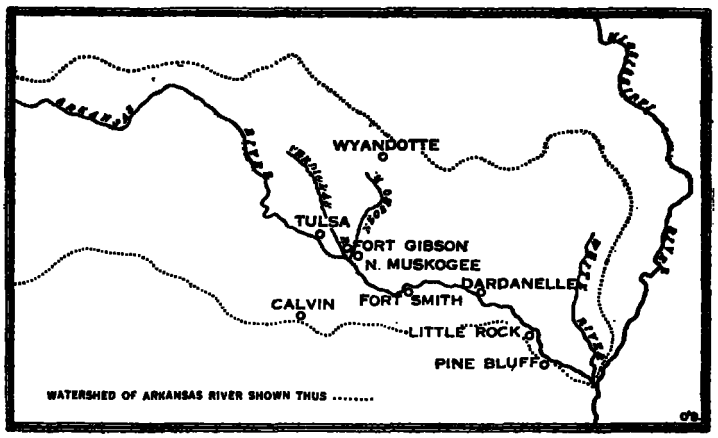

FIG. 1.—Location map of the lower Arkansas River.
["Verdigras" should be "Verdigris R."]

The distance from Fort Smith, Ark., to Dardanelle, Ark., is about 108 miles and the difference in elevation is 91.3 feet, giving a fall of 0.85 foot per mile. The distance from Dardanelle to Little Rock, Ark., is about 87 miles and the difference in elevation is 64.1 feet, giving a fall of 0.74 foot per mile. The distance from Little Rock to Pine Bluff is about 67 miles and the difference in elevation is 43 feet, giving a fall of 0.64 foot per mile.

The average time interval required for a rise to travel from Fort Smith to Dardanelle is about 1½ days; from Dardanelle to Little Rock, about 1 day; and from Little Rock to Pine Bluff about 1 day. There is a difference of about 50 per cent, possibly more, in the velocity of the current between a high and a low stage, the high stage of course having the greater speed, and this fact must be considered when making a river forecast.

TABLE 1.—*Flood stages and varying widths of the Arkansas at four points.*

Station.	Flood stage.	Width of river.	
		Low water.	Bankful stage.
	Feet.	*Feet.*	*Feet.*
Fort Smith, Ark.	22	600	2,320
Dardanelle, Ark.	20	800	2,340
Little Rock, Ark.	23	1,400	1,570
Pine Bluff, Ark.	25	610	1,600

The watershed on the north side of the Arkansas River in the Fort Smith and Little Rock districts is mountainous, and the streams fill quickly and run out rapidly: on the south side the watershed is more level and the streams rise more slowly and high stages continue longer.

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I. STAGE FORECASTS FROM RAINFALL ONLY.

As soon as a heavy rainfall is reported it is important to advise the public as early as possible as to the highest stage that may be expected in the river. This advice must be based upon the amount of rainfall that has been reported, since the forecast must be made before the water has had time to get into the rivers. If a sufficient number of stations were established to give an approximately correct average distribution of rain in the district, it would be possible to estimate closely the height of the resulting flood wave in the river. However, with the present small number of reporting stations it is possible to forecast the crest stage at Dardanelle about 2 days in advance, at Little Rock about 3 days in advance, and at Pine Bluff about 4 days in advance, and generally to within 1 or 1.5 feet of the stage that will be reached.

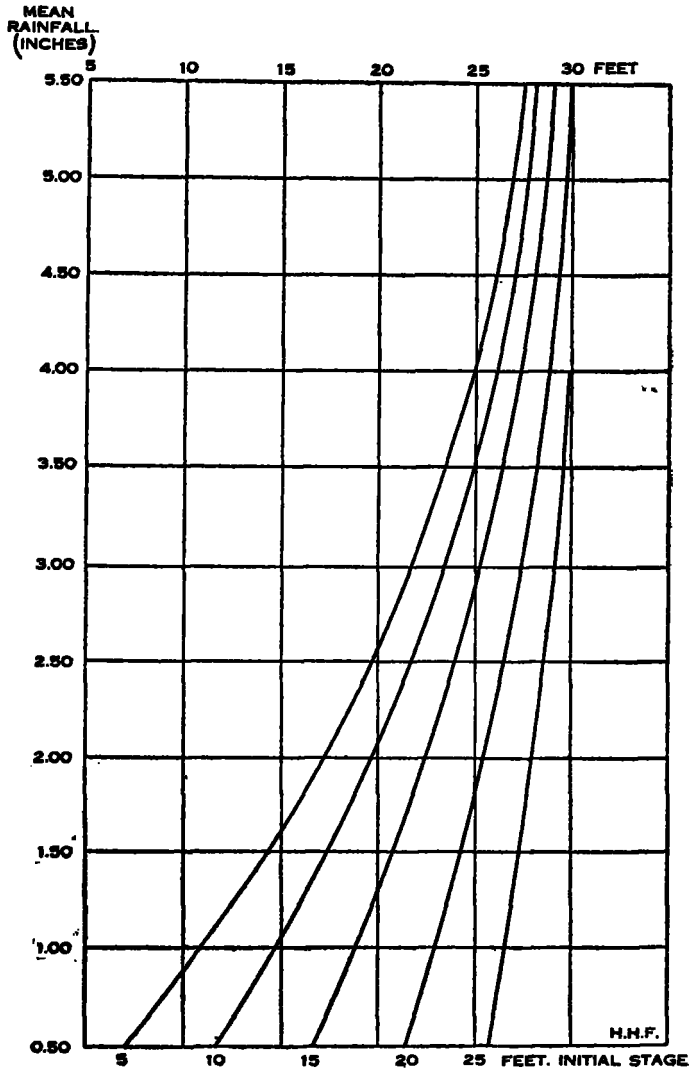

FIG. 2.—Graphs showing the crest stages at Dardanelle, Ark., for various mean rainfalls in the district. (The scale of figures 2 to 4 as here given is too small for a convenient working model. The horizontal scale should be about double that shown.)

Use of diagrams explained.—By plotting the mean rainfall over the district as ordinates and the crest stages as abscissæ, curves have been drawn for Dardanelle, Little

Rock, and Pine Bluff, Ark., for initial stages of 5, 10, 15, 20, and 25 feet. (See figs. 2, 3, and 4.)

In practice, the mean rainfall over the watershed is obtained by taking the arithmetical mean of the 24-hour rainfall as reported by telegraph from points in the watershed above the station for which the forecast is to be made. Thus if a forecast is to be made for Dardanelle, the mean rainfall is determined from the rainfall at Dardanelle and the amounts reported at stations in the Fort Smith district (see fig. 1). After determining the mean rainfall, enter the diagram on the left with the amount so found and note where the point of entry when carried horizontally across the sheet intersects the curve drawn for the "initial stage" at the beginning of the rain. The stage corresponding to that point is the crest stage to be expected at Little Rock 3 days later.

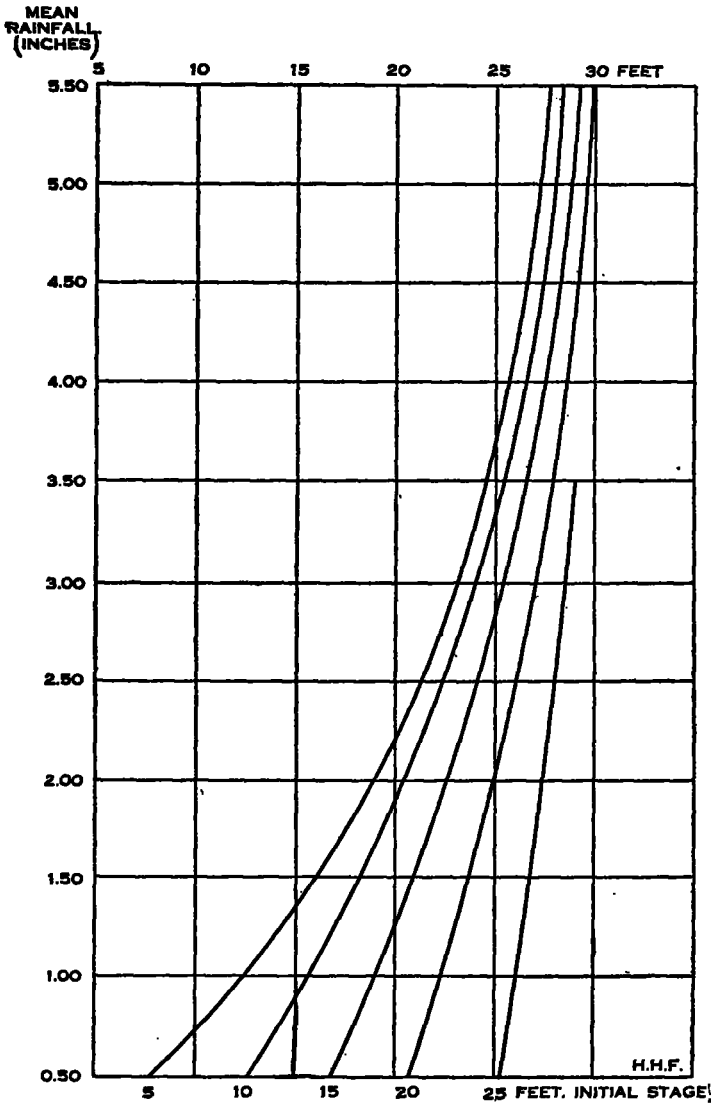

FIG. 3.—Graphs showing the crest stages at Little Rock, Ark., for mean rainfall in the district.

For initial stages other than those for which curves are given, interpolate between the curves.

Time period for crest stages.

1. Crest stage will generally reach Dardanelle in 2 days, Little Rock in 3 days, and Pine Bluff in 4 days after the rain if the rain has been general and evenly distributed.

2. If the rain is much heavier in the upper portion of the Fort Smith district than at Fort Smith and below, the crest stages will be about 1 day later than the times specified in the preceding paragraph.

3. If the rain has been much heavier at Fort Smith and below than above that place, the crest stages will be about 1 day earlier than the above, etc.

4. If the rainfall is much heavier in the vicinity of the point for which a forecast is made than above, the crest may occur on the same day as the rain.

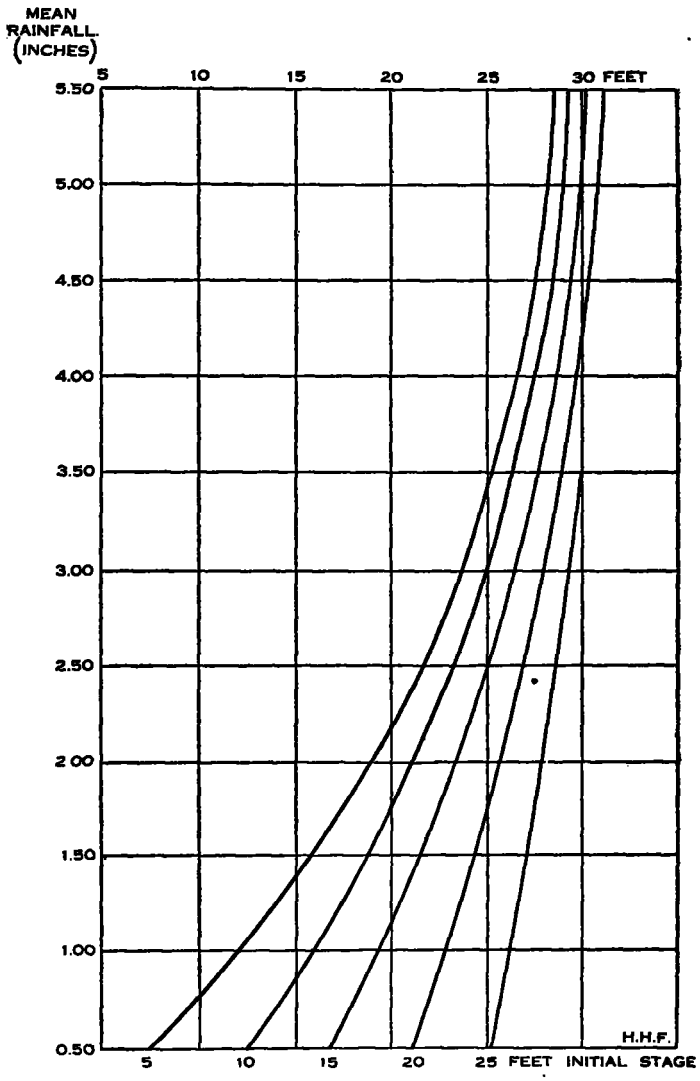

FIG. 4.—Graphs showing the crest stages at Pine Bluff, Ark., for mean rainfall in the district.

Distribution of rain.

5. When the rain begins over the upper portion of the watershed and moves down the river so that the water in the streams of the lower portion of the watershed reaches the river in time to meet the rise from upstream, it may cause a stage of from 1 to 3 feet higher than when the rainfall is evenly distributed, in point of time, over the entire watershed. However, the flood wave will be of shorter duration.

6. When the rain occurs first in the lower portion of the district and later in the upper portion, the crest may be from 1 to 2 feet lower than when the rain is simultaneously distributed, but the flood wave will be of longer duration.

7. When heavy rain occurs over only about one-fourth of the watershed use only about one-half to three-fourths the amount of heavy rain in making the district mean.

8. *Rain for several days in succession.*—When rain continues in the upper portion of the Fort Smith district for a longer time than it takes for the runoff to reach the station for which the forecast is made, use only three-fourths of the rain of the first day. If it continues for 2 days longer than the time period mentioned in paragraph 1, use one-half of the first and three-fourths of the second day's rain.

9. *Rain continuing for several days.*—A rain that extends over several days will not have as much effect as an equal amount falling in a short period of time. The forecaster should vary somewhat the amount indicated by the curves according to the character of the rainfall.

10. *Rainfall when the ground is dry.*—When the ground is very dry or is under cultivation, it will take up a great deal of water, especially if the rate of fall be moderate; use only one-fourth to one-half of the first inch of rain.

11. *Excessive rain.*—With excessive rate of rain the condition of the soil will not have much effect.

12. When heavy rain is indicated for the next day, add from 1 to 2 feet to the stage indicated, according to the amount of rain anticipated.

II. RULES FOR DAILY FORECASTS OF RIVER STAGES, GAGE RELATIONS, AND RAINFALL.

In order to make a daily forecast of river stages based upon the stages of the river at a station above, the upstream station chosen should be located as nearly as possible at a distance which will require 24 hours or a multiple thereof, for the flood wave to travel from that station to the station for which the forecast is to be made.

The forecast for Little Rock is based upon the stages at Dardanelle one day earlier, and figure 6 has been constructed by plotting rising stages at Dardanelle as ordinates and the stages 1 day later at Little Rock as abscissæ and drawing a mean curve through them. The actual plotted rises are given with the curve in order that the forecaster may see the extreme variations from the mean curve. It will be seen that there is an extreme range of about 4 feet on either side of the mean curve for stages below 20 feet, while for stages above 20 feet the range is about half as large. This is due to the fact that the time interval is not exactly 24 hours, but is probably 30 to 36 hours at low stages and about 18 to 24 hours at high stages. It also depends on the origin of the rise, whether caused mainly by rains above Dardanelle, by a uniformly distributed rain, or by rain mostly at Dardanelle and below. In order to meet the special conditions as they arise, certain modifications are necessary, and the following rules have been prepared to aid in determining what modifications are necessary to meet these special conditions as they arise. In making corrections for rainfall the mean of the rain at Dardanelle and Little Rock is used.

13. *Tributary streams.*—If the tributary streams are low a great deal of water will back up into them and cause the stages on the main stream to be as much as 1 to 2 feet lower than the average as the rise passes downstream.

14a. *Rainfall when the ground is dry.*—When the ground is very dry, or is under cultivation, it will take up a good deal of water, and a rainfall of as much as 1 inch will have very little effect unless it falls in a very short time. Add about 0.5 to 1.5 feet for an inch of rain, according to the condition of the soil and the rapidity of the rainfall.

14b. If the rate of rainfall is very excessive the dryness of the soil will have very little effect, and almost the full allowance for rainfall should be given.

15. *Rainfall when the ground is moist.*—When the ground is moist and the river is below 20 feet, add from 1 to 2 feet for an inch of rain, according to the amount and the rapidity of the rainfall. For stages above 20 feet gradually lessen the amount of the correction for rainfall until at 25 feet, when but little should be allowed.

16. *Local showers.*—Local showers and thunderstorms are usually of very limited extent and will have but little effect, even when the precipitation is excessive.

17. *Rainfall anticipated.*—When heavy rain occurs in the vicinity of Little Rock early in the day it may cause a rise of 1 or 2 feet at that place the same day, and it is necessary to make an allowance for rain that is expected to occur early in the day. Add from a few tenths to as much as 2 feet, according to the amount of rain that is expected.

18. *Rainfall soon after the observation.*—When rain falls soon after the morning observation, the larger part of it will generally reach the river by the next morning, and in such events no correction for rainfall should be made.

19. *Rapid rise at Dardanelle.*—When the river rises *rapidly* at Dardanelle it will not cause as high a stage at Little Rock as that indicated by the diagram. For a rise of 4 to 8 feet subtract about one-tenth of the rise at Dardanelle.

20. *Rapid fall at Dardanelle.*—When the river falls rapidly at Dardanelle it will not cause as low a stage at Little Rock as that indicated by the diagram by as much as about one-twentieth to one-tenth of the fall at Dardanelle, according to the rapidity of the fall.

21. *Cumulative corrections.*—When a rise sets in and it departs from the average relation as shown by the diagram, the departures are generally quite uniform, and the corrections necessary to be applied are quite accurately found by carrying forward from day to day the algebraic sum of the departure from the preceding forecast and all corrections applied for that forecast, except rainfall corrections. (Rules **14** to **18**, inclusive.) The rainfall at the two stations has largely produced its effect upon the stages at the lower station for which the forecast is being made by the end of the 24-hour period, and thus need not be considered on succeeding days. The sum of the corrections used as indicated above is designated the "cumulative" correction and will be so referred to in the examples following. As the river nears the crest stage the cumulative correction should be rapidly lessened.

22. *Falling river.*—The cumulative correction will be carried forward with a falling river. As the river falls to near flood stage a minus correction will generally lessen and as the river passes below flood stage the correction will generally change to a plus correction.

Figure 5 gives the average relation of the river stage at Fort Smith to the stage at Dardanelle 24 hours later. It will be noted that the extreme range for stages above 18 feet at Fort Smith is about the same as at Little Rock (fig. 6), but for stages at Fort Smith below 18 feet the range is greater. There are a few instances where the stage at Dardanelle was 8 feet, and in one instance it was 14 feet, above the average relation as shown by the figure. The latter stage was caused by torrential rains north of Fort Smith and Dardanelle, and the river

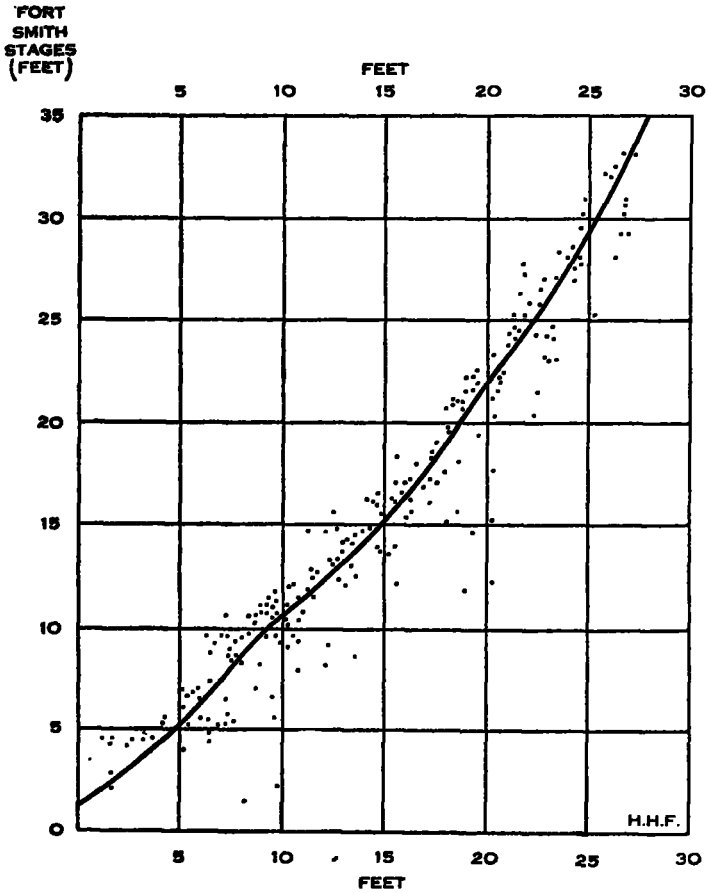

FIG. 5.—Graph showing the mean river stages at Fort Smith, Ark., and the corresponding stages at Dardanelle, Ark., 24 hours later.

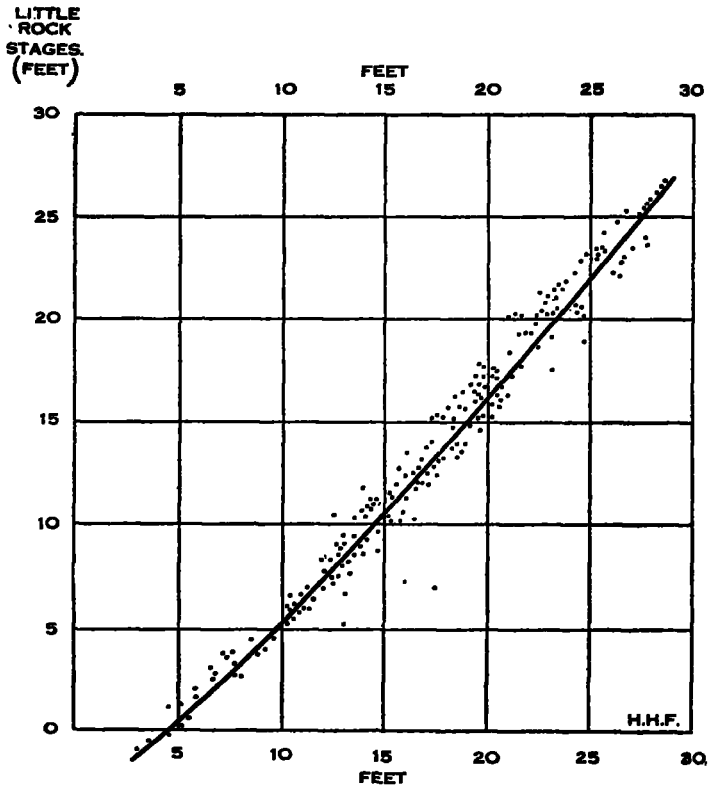

FIG. 7.—Graph showing the mean river stages at Little Rock, Ark., and the corresponding stages at Pine Bluff, Ark., 24 hours later.

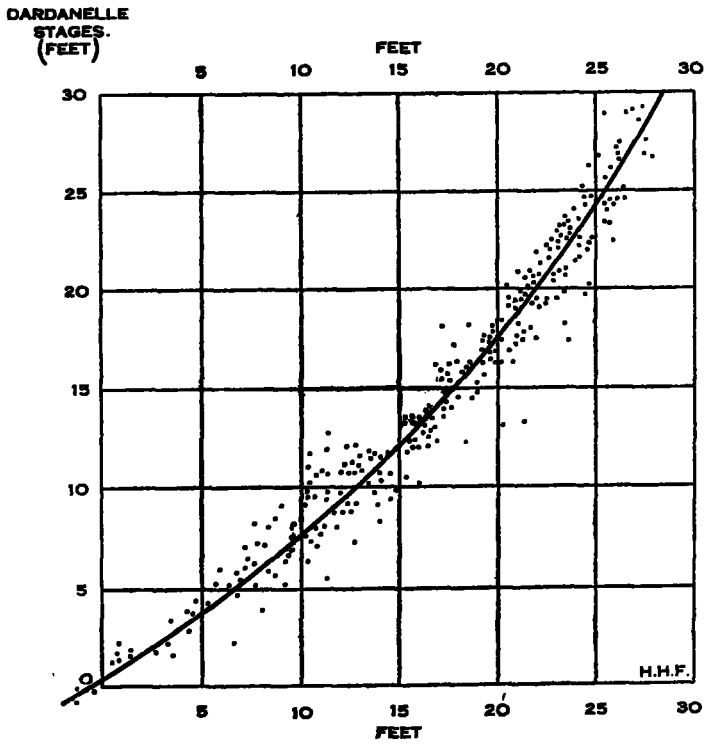

FIG. 6.—Graph showing the mean river stages at Dardanelle, Ark., and the corresponding stages at Little Rock, Ark., 24 hours later.

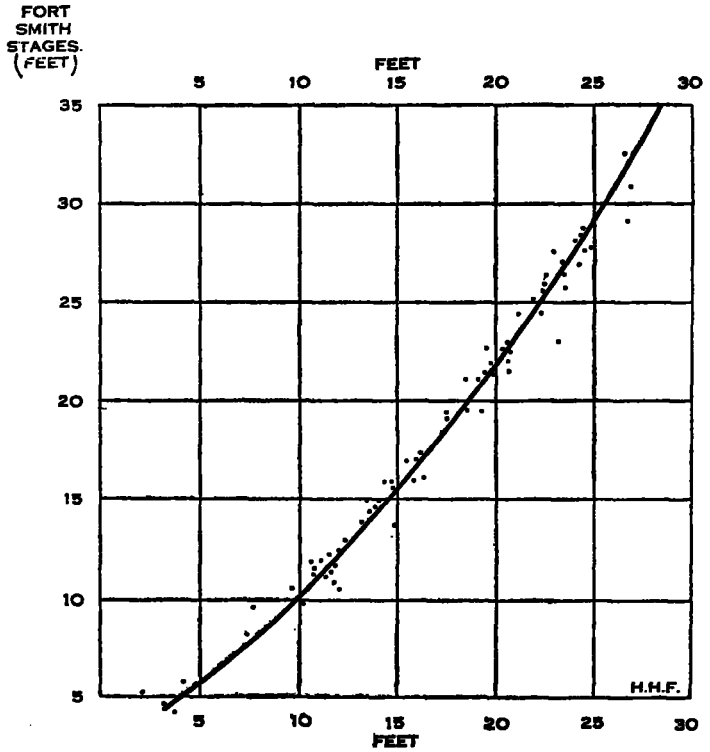

FIG. 8.—Graph showing the crest stages at Fort Smith, Ark., and the corresponding crest stages at Dardanelle, Ark., generally about one and one-half or two days later.

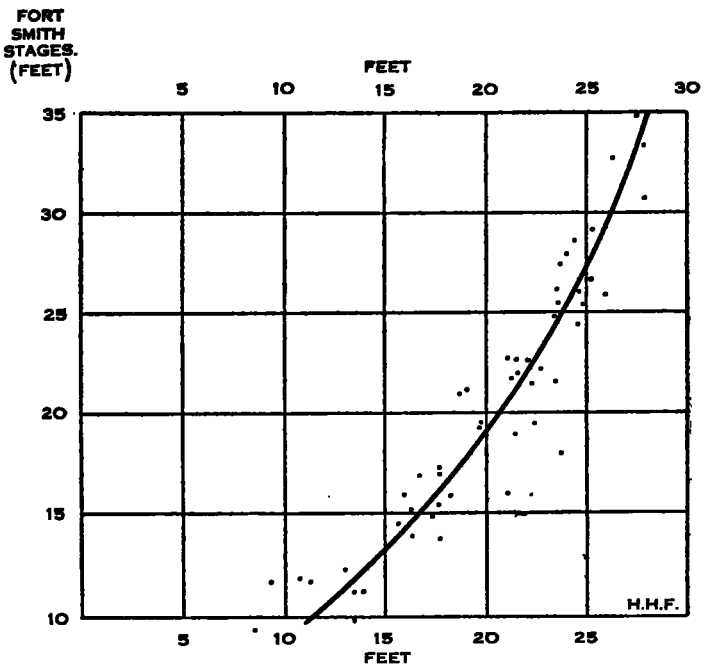

FIG. 9.—Graph showing the crest stages at Fort Smith, Ark., and the corresponding crest stages at Little Rock, Ark., generally about two days later.

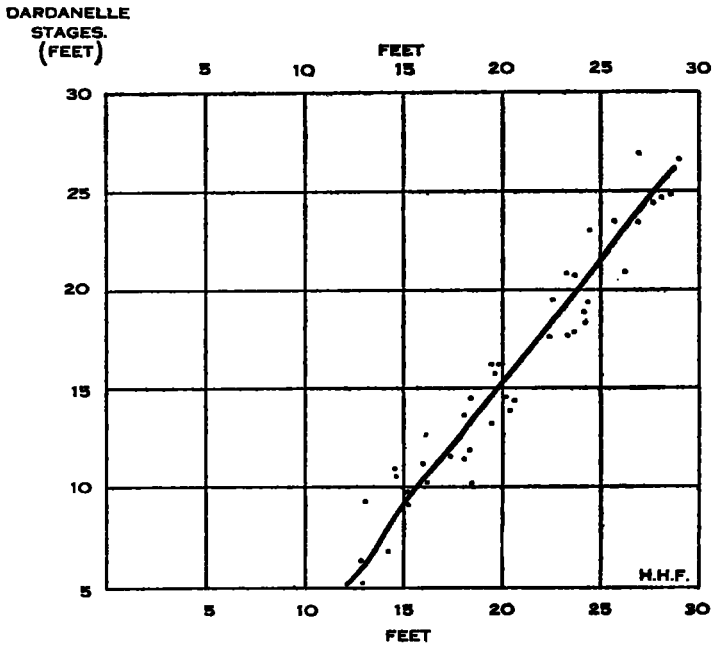

FIG. 11.—Graph showing the crest stages at Dardanelle, Ark., and the corresponding crest stages at Pine Bluff, Ark., generally about two days later.

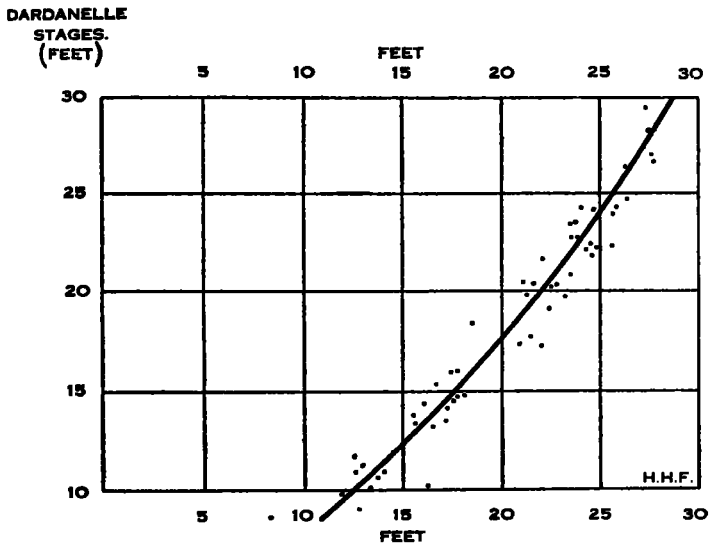

FIG. 10.—Graph showing the crest stages at Dardanelle, Ark., and the corresponding crest stages at Little Rock, Ark., generally one day later.

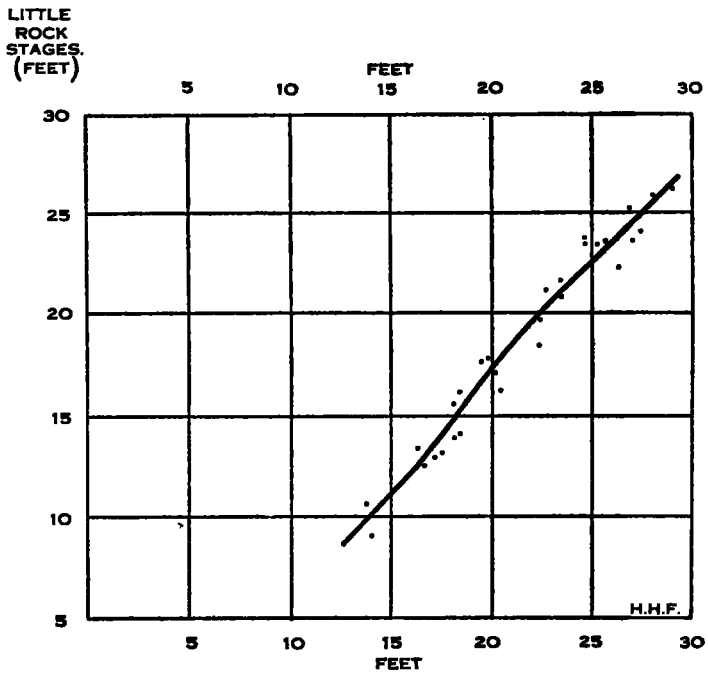

FIG. 12.—Graph showing the crest stages at Little Rock, Ark., and the corresponding crest stages at Pine Bluff, Ark., generally one day later.

rose simultaneously at both stations, the rise at Fort Smith being 17.4 feet and at Dardanelle 14.1 feet.

Figure 7 gives the average relations between the stages at Little Rock and Pine Bluff 24 hours later. The extreme range from the curve drawn for this station is somewhat less than for Little Rock.

The rules given for Little Rock will apply to Pine Bluff and Dardanelle, substituting the names of the two stations to be used for the two in the Little Rock rules, except that for sudden rises of 6 to 8 feet or more at Fort Smith Rule 21 should not be used for the first two days.

Figure 8 gives the crest stages at Fort Smith and the corresponding crest stages at Dardanelle about 1 day to 1½ days later. Figures 9 and 10 give the crest stages at Fort Smith and Dardanelle and the corresponding crest stages at Little Rock about 1 and 2 days later, respectively. Figures 11 and 12 give the crest stages

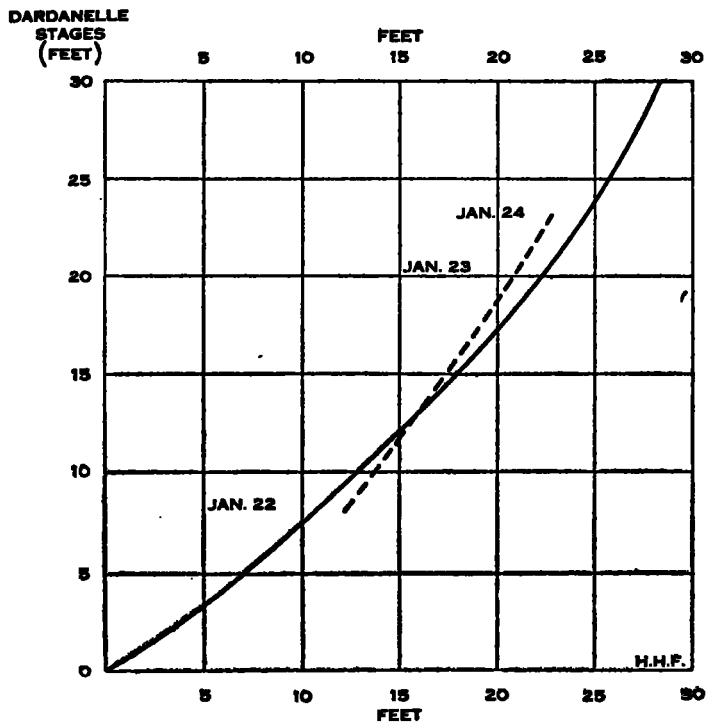

FIG. 13.—Normal curve (solid) for Dardanelle and Little Rock from fig. 6 and a graph showing the rise in January, 1916, and its departure from the normal.

at Dardanelle and Little Rock and the corresponding crest at Pine Bluff about 1 and 2 days later, respectively.

It will be seen from an examination of the plotted crest stages in the diagrams that the extreme range from the average curve is much less for a crest stage than for the daily stages. This is due to the fact that in plotting the daily stages an arbitrary time interval of 24 hours is used, from which each flood may vary in a greater or lesser degree in accordance with varying velocities of stream flow. In plotting crest stages the time interval is not considered; thus one of the two factors that must be considered in preparing the daily 24-hour forecast is eliminated, and the accuracy of the crest-stage forecast is thereby increased.

23. When the rain begins upstream and follows down the river, or when heavy rain occurs in the vicinity of the lower station so that it reaches the river on the arrival of the crest from upstream, add from 0.5 to 1.5 feet to the crest indicated by the curve.

24. When but little rain has fallen at both stations and heavy rain has fallen in the upper portion of the district, subtract a like amount.

25. In forecasting stages based upon the height of the river at an upstream station it will be found very helpful to draw the normal curve for the relations of the two stations on cross-section paper, as shown in figures 5, 6, and 7, and upon this sheet to plot the rise from day to day. The departure of the curve of the plotted rise from the normal curve is thus graphically shown and the manner in which the flood under consideration is departing from the average becomes apparent. It will be found that this departure is fairly presistent and may be used as a correction to be applied to the crest stage indicated by diagram to obtain the forecast crest stage. (See fig. 13.)

EXAMPLES.

1. Little Rock, January 24, 1916, figure 13.

On January 24 the plotted stage was 1.8 feet less than that shown by the normal curve of gage relations. By figure 10 the crest to be expected at Little Rock, for a crest at Dardanelle of 23.3 feet is 24.3 feet. Subtracting from this stage, obtained by figure 10, the departure from the normal as shown on the plotted daily stages (1.8 feet) we obtain 22.5 feet as the forecast crest stage for Little Rock. The actual crest was 22.6 feet, or 0.1 foot higher.

TABLE 2.—*Illustration of the use of figure 3 for forecasting crest stages at Little Rock, Ark.*

Date.	Mean rainfall.	Sum of rainfall.	Initial stage.	Stage by diagram.	Correction.	Rule.	Forecast stage.	Actual stage.	Departure.
1899.	*Inches.*	*Inches.*	*Feet.*	*Feet.*	*Feet.*		*Feet.*	*Feet.*	*Feet.*
May 6	2.00	.....	10.0	20.9	1.5	12	22.4	[1] 22.9	0.5
7	1.23	3.23	.....	24.6	.....	.....	24.6	[1] 24.5	−0.1
1908.									
May 22	0.31	.....	16.6	.....	.....	.....	.....	.....	.....
23	0.95	1.26	.....	21.3	2.0	12	23.3	[1] 23.6	0.3
24	[3] 1.28	2.54	.....	24.8	.....	.....	24.8	[1] 25.0	0.2
1908.									
May 29	0.68	.....	25.9	26.0	.....	.....	26.0	[3] 26.2	0.2
30	0.45	1.13	.....	26.4	.....	.....	26.4	26.2	−0.2
1916.									
Jan. 21	1.97	.....	8.0	20.2	.....	.....	20.2	[4] 21.0	0.8
22	0.30	2.27	.....	21.6	1.0	[5]	22.6	[4] 22.6	0
27	1.69	.....	22.0	24.2	.....	.....	24.2	[4] 24.0	−0.2
28	0.41	2.10	.....	25.4	.....	.....	25.4	[4] 25.3	−0.1
29	0.52	2.62	.....	26.2	.....	.....	26.2	[4] 26.3	0.1
30	0.52	[6] 2.71	.....	26.8	.....	.....	26.8	[4] 26.8	0
31	0.80	[6] 2.99	.....	27.1	.....	.....	27.1	[4] 27.3	0.2

[1] 4 days later.
[2] Rule 7.
[3] 1 day later.
[4] 2 days later.
[5] 1.25 inches at Little Rock.
[6] Rule 5.

Figure 3 has been prepared for use in forecasting crest stages from rainfall alone. Twelve rules for the guidance of the forecaster have been prepared, Nos. **1** to **12**. It will be clear from these rules that the time of the occurrence of the crest stages can not always be definitely announced, but the crest stage can be determined with reasonable accuracy except when the amount of rainfall in the ensuing 24 hours can not be accurately foreseen. In preparing the example submitted the writer had the advantage of a knowledge of the amount of rainfall in the ensuing 24 hours and therefore was able to fix the correction for anticipated rainfall with greater accuracy than would be possible in actual practice.

2. May 6, 1899.

Enter the diagram on the left with a mean rainfall of 2 inches and an initial stage of 10 feet. The correction for anticipated rainfall is placed at 1.5 feet (Rule **12**). This amount, added to the indicated stage by diagram (20.9 feet), gives 22.4 feet as the crest stage at Little Rock. The rain continued, however, and on the morning of the 7th the mean rainfall was 1.23 inches which, added to the mean for the 6th, gives the sum of mean rainfall, 3.23 inches. This amount gives, by diagram, a stage of 24.6 feet. The actual crest stage at Little Rock 4 days later was 24.5 feet.

3. May 22, 1908.

The mean rainfall on May 22, 1908, was too small materially to affect the rivers; on the 23d a mean rainfall of 0.95 was added to 0.31 inch, the mean for the 22d, giving 1.26 inches for the two days. There was additional rainfall in prospect for which a correction of 2 feet was allowed. The stage indicated by diagram (21.3 feet) plus the correction (2 feet) gives a forecast stage of 23.3 feet. Rain continuing, a new forecast was necessary on the morning of May 24. The mean rainfall was 1.98 inches, but as excessive rain occurred at only three stations, only one-half of the excessive rain was used, and the mean rainfall for the district was thus computed as 1.28 inches. Adding this to the sum of the mean rainfall for the 23d, we have 2.54 inches. When excessive rainfall occurs in only a portion of the district, the forecaster must determine whether to use 0.5, 0.6, 0.7, or 0.8 of the excessive amounts, according to the percentage of the district over which heavy or excessive rain occurs. The indicated stage by diagram, for 2.54 inches, with the initial stage of 16.6 feet, is 24.8 feet. The actual stage 4 days later was 25 feet, or 0.2 foot higher. The record for May 29 and 30, 1908, is given (see Table 2) to illustrate a case where the rainfall was moderate and the river was already at a high stage; hence no correction for rainfall was deemed necessary.

4. January 22, 1916.

On January 22, 1916, a correction of 1 foot was made under Rule **5**, because the rainfall was heavy in the upper portion of the district on the 21st and heavy at Little Rock on the 22d.

Daily forecasts for Little Rock, based on Dardanelle stages and rainfall at both stations.

A method will now be illustrated for making daily stage forecasts for Little Rock, Ark., by using the gage readings at Dardanelle, 87 miles upstream, in connection with the rainfall at the two stations.

As stated on page 145, rising stages at Dardanelle have been plotted as ordinates and the stages one day later at Little Rock as abscissæ, and a mean curve has been drawn through the data so plotted (fig. 3). The modifications due to one cause or another have been embodied in 10 rules numbered **13** to **22**, inclusive (see p. 145). An explanation of the practical working of the rules follows.

5. May 12 to 18, 1905.

Mean rainfall, Dardanelle plus Little Rock, is 0.16 inch. As the ground was dry no correction was made. As in the method first explained, however, a correction for anticipated rainfall was made and entered in column 9 as 1 foot.

TABLE 3.—*Illustrating daily river forecasts at Little Rock, Ark., by means of the gage heights at Dardenelle and the rainfall at both stations (fig. 6).*

Date.	Dardanelle stage.	Rainfall—			Stage by Fig. 6.	Cumulation corrections, Rules 21 and 22.	Rule.	Correction.	Rule.	Forecast stage.	Actual stage at Little Rock.	Departure.
		Fort Smith.	Dardanelle.	Little Rock.								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1905.	*Feet.*	*Inches.*	*Inches.*	*Inches.*	*Feet.*	*Feet.*		*Feet.*		*Feet.*	*Feet.*	*Feet.*
May 12	9.5	0.02	0.12	0.21	12.2			1.0	17	13.2	13.7	0.5
13	9.6	0.91	3.20	3.56	12.3	0.5	21	1.7	14	14.5	13.8	−0.7
14	13.7	0.32	0.20	0.22	16.7	−0.2	21	−0.4	19			
14								0.2	15	16.3	16.5	0.2
15	15.0				18.0	−0.4	21			17.6	17.8	0.2
16	14.5				17.3	−0.2	22			17.1	17.2	0.1
17	13.7				16.7	−0.1	22			16.6	16.3	−0.3
18	12.7				15.7	−0.4	22			15.3	15.4	0.1
1916.												
Jan. 22	8.2	0.05	0.54	1.25	10.4			1.8	15	12.2	12.5	0.3
23	20.3				22.4	0.3	21	−1.2	19	21.5	21.0	−0.5
24	23.1				24.5	−1.4	21			23.1	22.6	−0.5
25	23.2				24.0	−1.9	21			22.7	22.6	−0.1
26	22.3				24.0	−2.0	21			22.0	22.0	0
27	21.9	2.68	1.25	0.80	23.7	−2.0	22	0.8	14	22.5	22.6	0.1
28	25.2	0.26	0.80	1.19	25.8	−1.9	21	0.5	15	24.4	24.0	−0.4
29	27.5	0.11	0.75	1.44	27.4	−2.3	21	0.3	15	25.4	25.3	−0.1
30	29.0	1.50		0.02	28.0	−2.4	21			25.6	26.3	0.7
31	29.4	0.56	1.40	1.22	28.0	−1.7	21	0.4	15	26.7	26.8	0.1
Feb. 1	29.5			0.33	28.1	−1.6	21			26.5	27.3	0.8
2	28.8				27.7	−0.8	22			26.9	27.2	0.3
3	27.2				27.0	−0.5	22			26.5	26.3	−0.2
4	24.0	0.55			25.0	−0.7	22			24.3	24.4	0.1
5	18.5				21.0	−0.6	22	0.6	20	21.0	22.0	1.0
6	15.5			0.44	18.4	0.4	22	0.3	20	19.1	20.0	0.9
7	14.1				17.0	1.3	22			18.3	18.1	−0.2
8	13.0				15.8	1.1	22			16.9	16.8	−0.1
9	12.1	0.01		0.03	15.0	1.0	22			16.0	15.5	−0.5
10	11.4				14.3	0.5	22			14.8	14.3	−0.5

The indicated stage for Little Rock by diagram is 12.2 feet. To this is added 1 foot, as provided under Rule **17**, and the result is 13.2 feet, the forecast stage for Little Rock on May 13. The actual stage at that station was 13.7 feet, or 0.5 foot higher than the forecast stage.

May 13, 1905.—As explained in Rule **21**, the "cumulative" correction, the algebraic sum of the departure

from the preceding forecast and the corrections by Rules 13 and 19 to 22, inclusive, is carried forward each day. The mean rainfall, Dardanelle plus Little Rock divided by 2, is 3.38 inches. As the ground was relatively dry and the rainfall at Fort Smith was only 0.91 inch, the lowest rate or 0.5 foot rise for each inch of rain is assigned (Rule 14), which gives 1.7 feet (see Table 3, column 9). Adding the cumulative correction, +0.5 foot, gives 0.5+1.7=2.2 feet, the total correction to be applied to the stage indicated by the diagram figure 6, and 12.3+2.2=14.5 feet is the forecast stage for the 14th. The actual stage was 13.8 feet or 0.7 foot below the forecast stage.

May 14, 1905.—The cumulative correction, as before, is obtained by combining the corrections for the 13th in columns 7 and 13 (Table 3). As previously explained, the correction in column 9, being for rainfall, is omitted. Thus, −0.7+0.5=−0.2 is the cumulative correction to be carried forward. As the river rose rapidly (4.1 feet) at Dardanelle, one-tenth of this amount is entered as a minus correction in column 9 (Rule 19). A rainfall correction of +0.2 is also entered in column 9 (Rule 15). We have then −0.2, −0.4, and +0.2, or a total correction of −0.4 foot.

The stage indicated by figure 6, was 16.7 feet; subtracting the correction of −0.5 leaves 16.3 feet, the forecast stage for the 15th. The actual stage was 16.5 feet, or 0.2 foot higher.

May 15, 1905.—To get the cumulative correction for this date we take, as before, all of the corrections for the 13th except the rainfall correction. Thus (adding) −0.2, −0.4, and +0.2=−0.4.

The stage indicated by figure 6 is 18 feet. As there are no other corrections to be applied, we have 18.0−0.4=17.6 feet, the forecast stage for the 16th. The actual stage was 0.2 foot higher.

May 16, 1905.—Proceeding as before, we have (adding) +0.2, −0.4=−0.2 as the cumulative correction. That amount, deducted from the stage indicated by diagram, 17.3 feet, gives 17.1 feet as the forecast stage for the 17th. The actual stage was 0.1 foot higher.

May 17, 1905.—Combining as before, +0.1 and −0.2 equals −0.1 foot, the cumulative correction. Substracting this amount from the indicated stage, 16.7 feet, we have 16.6 feet as the forecast stage for the 18th. The actual stage was 16.3 feet, or 0.3 foot lower.

May 18, 1905.—The cumulative correction is −0.3+−0.1=−0.4. Subtracting this amount from the indicated stage, 15.7 feet, gives 15.3 feet as the forecast stage for the 19th. The actual stage was 15.4 feet, or 0.1 foot higher.

6. January 27 to 29, 1916.

The following examples show the lessening effect of rainfall on high stages of the river:

January 27, 1916.—A cumulative correction of −2 feet is brought forward from the 26th. As the river was high, but 0.8 foot rise was allowed for each inch of rainfall (Rule 15). Adding −2.0+0.8=−1.2 feet, the correction to the indicated stage. The stage indicated by diagram (fig. 6) was 23.7 feet. Hence 23.7−1.2=22.5 feet, the forecast stage for the 28th. The actual stage was 0.1 foot higher.

January 28, 1916.—Combining as before, we have a cumulative correction of −1.9 feet. As the river was high, but 0.5 foot was allowed for each inch of rainfall, which gives −1.4 as the total correction. This, subtracted from the indicated stage (25.8 feet), gives 24.4 feet as the forecast stage. The actual stage was 0.4 foot lower.

January 29, 1916.—Combining as before, we obtain a cumulative correction of −2.3 feet. As the river was very high, but 0.3 foot rise was allowed for each inch of rain. Adding: −2.3 and +0.3=−2.0 as the total correction, which, applied to the indicated stage, 27.4 feet, gives 25.4 feet as the forecast stage. The actual stage was 0.1 foot lower.

THE DISAPPEARANCE OF SNOW IN THE HIGH SIERRA NEVADA OF CALIFORNIA.

By ALFRED J. HENRY, Professor of Meteorology.

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Much effort has been put forth in many parts of the world, to determine the depth and distribution of precipitation in the form of snow, yet but little attention seems to have been given to the conditions attending the disappearance of snow. The ordinary conception that the snows of winter are melted by the increased insolation of late spring and early summer seems to be sufficiently close to the truth to satisfy the average inquirer.

The object of this paper is to determine whether the available records of snowfall made by cooperative observers, afford any insight into the weather conditions which may modify or control the disappearance of snow. The subject is, moreover, rather closely associated in the public mind with flood causation. Time was when the June floods in the Missouri River were considered as being due to the melting of winter snowfall at the headwater streams, but that impression is fast disappearing in the light of modern records of precipitation and streamflow for the headwaters of that stream. Floods in the rivers of New England and the tier of northern states extending thence westward to the Dakotas, are intensified by the snow cover which may be on the ground toward the end of spring. The release of the snow water, however, is not easily accomplished except the night temperatures be continuously above freezing for several consecutive days—a rather unusual condition in spring. Hence snow floods are rare even in the more northern rivers of the United States. In Washington and Oregon, due to the proximity of those states to the Pacific Ocean, warm winter rains sometimes fall upon a deep snow cover and floods result, but even in those states snow-melting weather during the winter and late spring is of infrequent occurrence. The most pronounced snow flood of the United States is that which annually passes down the Columbia River, due almost wholly to the melting of the snow cover at the higher altitudes of its drainage basin. The depth of the snow cover is usually fairly well known from observations made by snowfall observers of the Weather Bureau, supplemented by reports from cooperative observers, but the manner in which the snow cover will disappear, whether by slow melting and rapid evaporation or by rapid melting and quick runoff, can not be determined with any certainty far in advance.

In a study of this subject one naturally turns to the high Sierra of California, where a great amount of snow falls during winter and its disappearance during spring can be carefully observed. Reports of snowfall are available for a number of stations in that region, but we have confined our attention to three stations whose altitudes and geographical coordinates are shown below in Table 1.